The insecurity of Vale's dams in Minas Gerais, Brazil: applying activity theory to disaster analysis

A insegurança das barragens da Vale em Minas Gerais, Brasil: aplicação da teoria da atividade à análise de desastres

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Abstract

The objective of this article is to point out hypotheses of contradictions historically incubated in Vale's activity systems and that may have led to Brazil's biggest environmental disaster, the B I dam break in Brumadinho, and the interdiction of many other dams owned by Vale in the state of Minas Gerais, Brazil. This is a case analysis from secondary data available in interviews, documents, and texts published in different media between 2011 and 2021. We try to demonstrate, from the Historical-Cultural Theory of Activity, the contradictions verified in and between Vale's activity systems, since the company distributed large dividends to its shareholders, remunerated its directors as never before, reduced costs in relation to incomes, and brutally reduced internal debt, but keeping insufficient investments in dam management, culminating with the break of B I in 2019 and with 29 dams interdicted in March 2021. Financialization has become central to the company's operations. This study points to a methodological path of the interdisciplinary dialogue to help clarify how strategic managerial decisions, especially those of financial management, could influence the production, maintenance, and safety management of tailings dams.

Keywords: Dam Break; Occupational Accident; Mining; Financialization.

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Resumo

O objetivo deste artigo é apontar hipóteses de contradições que estariam incubadas historicamente nos sistemas de atividades da Vale, e que podem ter levado ao maior desastre ambiental do Brasil: o rompimento da barragem B I em Brumadinho, bem como à interdição de muitas outras barragens da empresa no estado de Minas Gerais, Brasil. Trata-se de uma análise de caso a partir de dados secundários disponíveis em entrevistas, documentos e textos publicados em diferentes mídias entre 2011 e 2021. Procuramos demonstrar, a partir da Teoria Histórico-Cultural da Atividade, as contradições verificadas em e entre sistemas de atividades da Vale, pois a empresa distribuiu dividendos vultosos aos seus acionistas, remunerou como nunca seus diretores, reduziu os custos em relação às receitas e diminuiu brutalmente a dívida interna, mas manteve investimentos insuficientes na gestão das barragens, culminando no rompimento da B I em 2019 e em 29 barragens interditadas em março de 2021. A financeirização tornou-se central para as operações da empresa. Este estudo aponta para um caminho metodológico do diálogo interdisciplinar que ajuda a esclarecer como as decisões gerenciais estratégicas, especialmente aquelas da gestão financeira, poderiam influenciar a gestão de produção, de manutenção e de segurança das barragens de rejeitos.

Palavras-chave: Rompimento De Barragem; Acidente De Trabalho; Mineração; Financeirização.

Introduction

Disasters caused by dams in mining are common, with 146 events worldwide between 1961 and 2022. In Brazil, in the state of Minas Gerais (MG) alone, eight events occurred from 1986 to 2022 (Wise, 2022).

On November 5, 2015, the Fundão Tailings Dam (BRF) - operated by Samarco Mineração S.A., a mining company controlled by Vale S.A. (Vale) and the Anglo-Australian BHP Billiton - broke in the municipality of Mariana, MG, Brazil, causing the death of 19 people. Despite the great repercussions of this disaster, on January 25, 2019, the break of the B I (B1) Tailings Dam at the Córrego do Feijão mine in Brumadinho, MG, also owned by Vale, took place, culminating in 270 deaths and 64 injured workers (Ministry of Economy, 2019). The disaster brought numerous social, economic and environmental consequences to the Paraopeba River region, with 315 km of rivers and 294 hectares of vegetation affected, in addition to damages to local agriculture, fishing and tourism (Arcadis, 2020).

We note that, despite the enormous impacts, mining dam failures occur rather often. But why does this happen? What are the root causes?

As in the 1980s, great disasters have become frequent in the 21st century and are explained by some authors as the aftermath of changes in the production process in the context of the global economy. This phenomenon is related to the introduction and intensification of information technology and automation, increased outsourcing and global competition, as well as the pressure for results to meet shareholders' demands (Metzger; Maugeri; Benedetto-Meyer, 2012; Dias; Lima, 2014).

Reason (1997) pointed out that the history of accidents begins with organizational factors - such as strategic decisions and generic organizational processes. These processes are outlined in view of the company's corporate culture and the way the organization conducts its business, with consequences transmitted to work environments. Rasmussen (1997) showed that a socio-technical system is forced by an accelerating pace of technological change, an aggressive and competitive environment, changing regulatory practices, and public pressure.

The aim of this article is to contribute to a systemic and organizational analysis of events, from the Cultural-Historical Theory of Activity (CHAT), in which accidents are understood as manifestations of contradictions within and between activity systems (Lopes; Vilela; Querol, 2018). We hypothesize contradictions that are historically incubated in the system and that may have contributed to the break of B1 and the interdiction of other Vale dams in MG, among them, the process of financialization that has intensified in the company since 2015.

This paper aims to answer the following: 1) What changes in Vale's management impacted dam safety and maintenance in the years prior to the B1 accident?; 2) What were the consequences of these changes for dam safety?; and 3) What contradictions led to and were created by these changes?

We begin with a brief introduction of the theoretical approach to how accidents are understood and analyzed. Next, we present the data and the analysis method, as well as show the Vale case and its financial management. Subsequently, we highlight the stagnation of low investments in dams and the interdiction of many of them, as well as pointing out changes in the way containment structures are managed and findings from the B1 disaster investigation. We end by discussing the hypotheses of historical contradictions within Vale.

Accidents as a manifestation of contradictions in and between activity systems

According to CHAT, the interaction of humans with the environment and with other humans occurs through the use of tools and signs. This interaction led to a specifically human form of activity and a new principle of development, based on cultural learning and the historical evolution of forms of mediation of human vital activities. In this theory, the basic unit of analysis is an activity system (AS) that represents the multiple culturally mediated relations of human activity. The activity subjects use instruments, community, rules, and division of labor to interact with the object. The object defines the activity, it is the purpose of the AS, which motivates and defines the horizon of possible goals and actions (Virkkunen; Newnham, 2015).

An AS takes shape and is transformed over long periods. It is only possible to understand an organism as a function of the interactions that occur within its world of life and the history of its evolution (Virkkunen; Newnham, 2015).

In this approach, accidents are understood as manifestations of contradictions, which are not problems or conflicts, but historically accumulative structural tensions within and between AS (Lopes; Vilela; Querol, 2018). They manifest themselves as disturbances, disruptions, and wastage in the process by which the activity is carried out, as well as conflict and disagreement between individuals. A primary contradiction exists in each component of the core activity and refers to the relationship between the exchange value and the use value of these components. In Marxist theory, the value of the object produced simultaneously meets two conditions: it has a market value - called exchange value - and a use value, to meet human needs. A secondary contradiction means that two elements within the AS are incompatible, therefore setting contradictory demands for actions by individuals in the system (Virkkunen; Newnham, 2015).

It is not uncommon for several activities to be involved in the realization of an object, i.e., there may be two or more AS in the co-construction of a potentially shared object (Virkkunen; Newnham, 2015). We will see later that B1 was such a shared object.

The contribution of CHAT to accident analysis and understanding risks in complex systems is recent. In Brazil, Lopes, Vilela, and Querol (2018) used CHAT to explain the contradictions that contributed to the occurrence of a fatal accident at an airport construction site.

Material and methods

This is a case study that addresses the tailing dams owned by Vale in MG, based on secondary data available from interviews, documents and texts published in different media.

These publications cover the period between 2011 and 2021, among them: two reports from the

State Foundation for the Environment (FEAM), five reports from the National Mining Agency (ANM), the occupational accident analysis report from the Regional Labor Superintendence of MG (SRT/MG), 11 financial reports and two sustainability reports from Vale, two requests for suspension of dam interdictions sent by Vale to the SRT/MG, and five documents extracted from Vale's website. We also sent Vale, by electronic means, four questions about the management of B1. One of the authors was granted authorization by the Regional Labor Superintendent of Minas Gerais to use any documents referring to the inspection of dams at Vale.

The analysis of the material was done based on the concepts of the CHAT and the sociotechnical approach. We point to the historical changes that led to the financialization of Vale and the compromising of dam management, which may have a proximal or distal relationship to the Brumadinho disaster, and the interdiction of numerous other tailings containment structures owned by the company.

The Vale case

Vale, Brazil's leading mining company and the world's largest in iron ore production, had 150 dams and dikes designed to contain tailings, sediments, and water in the country in 2017 (Vale, 2017b; 2018b).

In March and September of each year, it is up to the mining companies to hire an auditing company to certify the safety of their dams and issue the Declaration of Stability Condition (DCE) (Brazil, 2017). Since the B1 break, the company has failed to achieve DCE for many of its dams in MG (Brazil, 2019; 2020a; 2020b; 2021a; 2021b; Vale, 2019c). The last information made available by the ANM about dams in Brazil pointed to 23 structures of Vale being interdicted in September 2022, all in Minas Gerais (Brazil, 2022).

In order to try to understand what reasons led to the collapse of B1 and the failure to obtain DCE for the other dams, it is necessary to look at the profound changes that have occurred in Vale over time. Among these: the implementation of measures to satisfy the financial market, such as the reduction of operating costs and the company's net debt; as well as the increase in the distribution of dividends to shareholders. One of our hypotheses of contradiction is that insufficient resources have been invested in the management of dams to keep them safe.

Financial management and the new CEO

Vale's internationalization strategy, carried out during Roger Agnelli's tenure as CEO, coincided with the *commodities boom* between 2002 and 2011. In the *post-boom*, iron ore had a sharp retraction in its price, forcing mining companies to change their strategies, among them reducing operating costs and increasing productivity (Wanderley, 2017, p. 3).

According to Milanez et al. (2019), from 2015 on, significant changes occurred in Vale's structure, such as the choice of a new CEO, Fábio Schvartsman, in 2017, an executive with extensive experience in the financial sector and in companies in the manufacturing industry. The company has implemented a process of change directly related to the requirements of the financial market.

Vale increased the ratio of operating cost to net operating revenue to 80.2% during 2015, mainly due to the low value of iron ore in the international market, which reached an average price of US$44.61 per ton, compared to US$75.43 in 2014. It managed to reduce it significantly to 64.2% in 2016, until it reached 46.7% in 2020, a percentage even lower than in 2013 (Table 1).

The fixed compensation of Vale's executive officers (EO) varied little from 2011 to 2014 and then dropped 22.7% from 2014 to 2015 (Table 2). Variable compensation came falling from 2011 to 2015 and plummeted in 2016 due to the BRF break. However, in 2017 there was a growth of approximately 13.5 times compared with the previous year.

As of 2018, the way EO compensation was presented in the annual report changed. Total compensation grew over the years, except for 2019 - the year of the B1 break: R$166.1 million (mi) in 2018, R$85.40 mi in 2019, R$165.42 mi in 2020 and R$246.49 mi in 2021 (Vale, 2019a; 2020; 2021b; 2022b). Despite the 2019 disaster and the worldwide

repercussions of the case, EO pay almost tripled between 2019 and 2021.

As for the distribution of dividends and interest on equity to shareholders, the amount fell between 2011 and 2014, due to the sharp drop in the average price of a ton of iron ore. It plummeted to $0.25 billion (B) in 2016, still because of the falling value of the *commodity* and the BRF break in 2015. The promise in 2017 by the new CEO has been fulfilled, namely: "in the coming years there will be no other (mining company) producing more value for its shareholders than Vale." From 2015 to 2021, the amount distributed to shareholders grew ninefold (Vale, 2012; 2013; 2014; 2015; 2016; 2017a; 2018a; 2019a; 2020; 2021b; 2022b).

Table 1 - Vale's operating cost and net operating revenue (2013-2020).

Period	Operating cost[1] (US$ Million)	Net Operating Revenue[2] (US$ Million)	Operating cost / operating revenue (%)
2013	24,245	46,767	51.8
2014	25,064	35,124	71.3
2015	18,751	23,384	80.2
2016	17,650	27,488	64,2
2017	21,039	33,967	61.9
2018	22,109	36,575	60.4
2019	21,187	37,570	56.4
2020	19,039	40,018	47.6

Source: Vale, 2014; 2015; 2016; 2017a; 2018a; 2019a; 2020; 2021b.
Notes: 1: the cost of goods sold and services rendered. 2: is the amount the company actually receives for the sale of its products.

Table 2 - Compensation of Vale's executive officers in US$ million (2011-2017)

Type of compensation/year	2011	2012	2013	2014	2015	2016	2017
Fixed remuneration and benefits in cash	11.7	11.3	11.4	12.3	6.42	7.27	7.6
Variable remuneration	25.3	17.4	9.7	12.9	7.29	0.98	13.24
Pension, retirement or similar benefits	2.1	2.1	2.1	1.2	1.24	1.47	1.53
Indemnities	59.0	14.5	0.5	0.0	5.41	4.66	20.19
Social contributions	19.1	8.3	3.9	4.5	3.53	2.24	8.03
Total paid to executive directors	117.1	53.6	27.6	30.9	23.89	16.62	50.59

Source: Vale, 2012; 2013; 2014; 2015; 2016; 2017a; 2018a.

Regarding debt reduction, the company's net debt would fall from $18.143B at the end of 2017 to $9.650B at the end of 2018 (Vale, 2018a, 2019a).

The amount spent on maintaining Vale's operations decreased significantly between 2013 and 2017, from $4.6B to $2.2B (Vale, 2017b; 2018b), which may have also impacted dam management.

As seen, the financial strategy became central to the company's operations, suggesting that the operational dimension of its activities was losing relevance in the allocation of resources. We will demonstrate below that, as of 2015, investment in dam safety lagged far behind the pace of growth in EO compensation and profit distribution to shareholders.

Stagnant investment in dams

Vale reported that, in the period from 2016 to 2019, investments in dam management would total about US$ 221 mi applied in dam maintenance and safety actions, such as: maintenance, monitoring, improvement works, audits, risk analysis, reviews of action plans for mining dam emergencies (PAEBM), implementation of warning systems, video monitoring and instrumentation (Vale, 2019d).

From 2015 to 2016 there was an increase of US$3.53 mi in this management, equivalent to 12.7% (Vale, 2019d). This is a small figure when you consider that, with the BRF collapse in 2015, Vale should have turned on the 'warning sign' regarding its dams. Two consultants have been hired and studies have begun on liquefaction for the upstream elevated dams (Ministry of Labor, 2019), a phenomenon in which a saturated soil mass, usually loose sands or loosely plastic silts, loses much of its shear strength when subjected to static or dynamic loading, moving like a fluid. In addition, the Norte/Laranjeiras, Forquilha V, and Borrachudo II dams started operation in 2016, increasing management costs (FEAM, 2017; 2018).

From 2016 to 2017 there was an increase of US$25.28 mi (80.71%) in dam management (Vale, 2019d). Having as justification the DNPM Ordinance no. 70.389 of 2017 (Brazil, 2017), which brought a series of accessory obligations for mining companies with dams, among them the preparation of the periodic review of dam safety, the regular safety inspection report and the respective declarations of stability condition (DCE) twice a year, as well as the PAEBM, including flood studies commonly called *Dam Break*.

Vale contracted other technical studies, such as the "Geotechnical Risk Management," which included data consolidation and risk identification, probability calculation, *Dam Break* studies, and valuation of the consequences in case of dam break (Ministry of Economy, 2019). In addition, the Capitão do Mato and Barnabé 1 dams came into operation in 2017 (FEAM, 2017; 2018).

Due to the new obligations imposed by the DNPM, there was an expressive increase in management expenses, which does not mean the dams were secure. *Dam Break* and PAEBM studies, as well as the use of modern software to calculate the factor of safety (FS) do not make dams safer from a stability point of view. In addition to the physical maintenance of the dam, it is necessary to keep the water table as low as possible, i.e., keep it away from the dikes, as this has a direct influence on the calculation of the structure's stability FS. To do this, the internal and external drainage of the structure must be working to remove as much water as possible from its interior.

From 2017 to 2018, the cost of management increased by 16%, reflecting the requirements created by DNPM in 2017. Also impacting this value are the new elevations made in the dams between 2015 and 2018, increasing the costs with instrumentation, inspection and maintenance. From 2018 to 2019, the planned increase in the cost of dam management was only US$2.42 mi (Vale, 2019d). However, the company had to spend much more on the management of its dams after the B1 break, as we will see below.

There was a study for the decharacterization of B1, contracted with the company TÜV SÜD on September 21, 2018, with a completion deadline for February 18, 2019. A presentation, dated January 17, 2019, demonstrated all the work done by the contractor regarding the conceptual design and the choice of the closure alternative (Ministry of Economy, 2019). However, the effort would be in vain, as the dam would break eight days later.

We tried to obtain information from VALE about the amount invested in the management of B1 from

2015 to 2018, but the company said it was not possible to individualize such amounts in its internal systems before 2019, which made it difficult to analyze the historical evolution of B1's safety.

The interdiction of other dams

After the B1 break, the contracted external audit companies revised their concepts regarding the geotechnical parameters adopted for the stored tailings, which decreased the calculated FS. Numerous dams had no DCEs issued by the external auditors as of March 2019 (Vale, 2019c).

As a result, nine Vale dams have been interdicted by SRT/MG for bringing risks to workers (Cunha, 2019), they are (identified by the names of their mines): Forquilhas I, II and III, Marés II and Group (Fábrica); Sul Superior (Gongo Soco); B3 and B4 (Mar Azul); Maravilhas II (Pico); Vargem Grande (Abóboras). There was no interdiction of B1, as it was practically destroyed when the break occurred (Ministry of Economy, 2019).

Other structures were interdicted by the ANM: eight in March 2019 (Vale, 2019d), one in September 2019, six in March 2020, and eight in September 2020 (Brazil, 2019b; 2020a; 2020b). With the attested stability of B VI (Córrego do Feijão) in September 2020 and of Taquaras, Capim Branco and Menezes II in March 2021, Vale had 29 dams interdicted in MG (Brasil, 2020b; 2021a).

Problems occurred with upstream dams (11) - the most unsafe ones - as well as with downstream dams (6), centerline dams (2) or only single dikes (13). Even new structures, such as North/Laranjeiras (2016), Borrachudo II (2016) and Capitão do Mato (2017) failed to have their stability guaranteed, which may refer to construction problems.

Lack of stability in dams is mainly due to problems with the position of the water table. Cruz (1996) points out that "the art of designing dams seems to be the art of controlling the flow of water through the body and foundation of the dam, thus avoiding any chances of the soil being carried away by the water." The higher the position of the water table within the stored material or within the dikes themselves, the less secure the dam is, and this is one of the factors that contributed to the B1 break.

The change in dam management

Since the interdictions of its dams, Vale has begun to implement microseismic stations, interferometric radars, monitoring using orbital radars, electroresistivity tests and small works - such as directing the flow of water out of the reservoirs - in addition to beginning new geotechnical campaigns to learn more about its structures, all good engineering recommends.[1, 2]

Additionally, the Geotechnical Monitoring Center (CMG) in Nova Lima/MG went into operation, where professionals stand in front of monitors 24 hours a day and are alerted if any significant changes occur in the pre-established safety parameters (Vale, 2019b).

Due to ANM's determination (Brazil, 2019a) for the decommissioning of elevated upstream dams, Vale put in place a plan to dismantle 30 dams, with US$2.625B (Vale, 2020; 2021b; 2022b) provisioned in 2019 for such. The amount spent on decommissioning in 2021 ($338 mi) was five times greater than Vale's forecast for dam management in 2019.

Investigation of the causes of the B1 break

The investigation of the B1 break showed that there was an interruption of operation and unusual instrument readings, as well as a lack of compliance with recommendations coming from safety inspection reports, failures in the maintenance of drainage, issuing of the DCE - despite the FS stability being lower than established in international standards and/or suggested by consultants -, entry of data in the ANM's Information System for

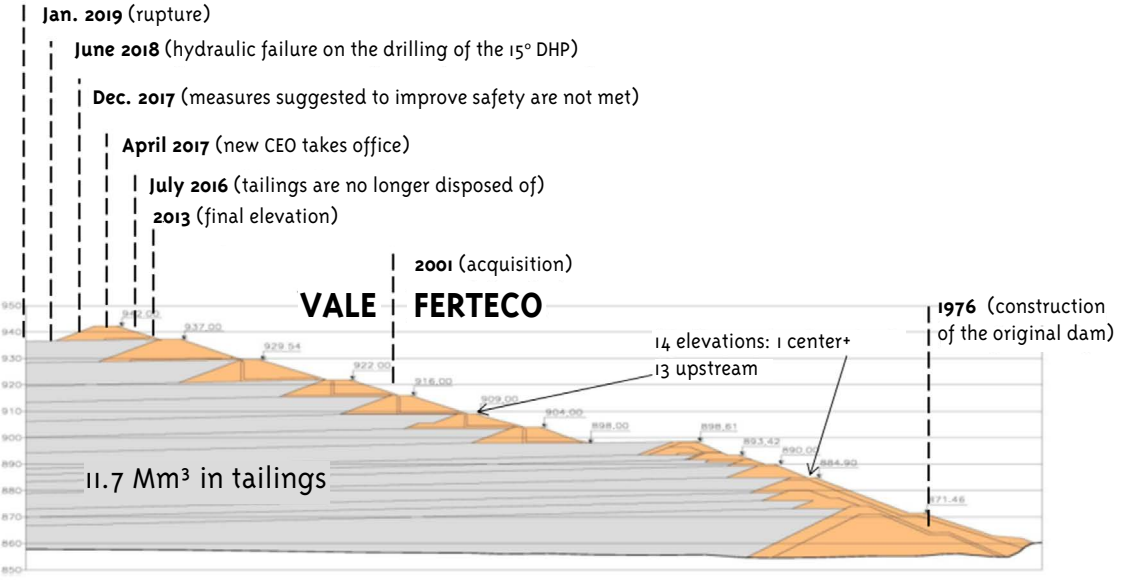
1 VALE. *Request for suspension of the interdiction of the Maravilhas II dam to the Regional Labor Superintendence in Minas Gerais.* Belo Horizonte, 2019.

2 VALE. *Request for suspension of dam interdiction at the Fábrica Mine to the Regional Labor Superintendence in Minas Gerais.* Belo Horizonte, 2019.

Management of Mining Dams (SIGBM) disconnected from reality, as well as the susceptibility of the tailings to liquefaction (Ministry of Economy, 2019). However, Vale's assessment of the supposed safety of the dam has not changed.

Vale was slow to implement measures that could help with water withdrawal from the B1. Remedial measures, such as the construction of reinforcement berms, vertical drainage wells, etc., were pointed out as recently as 2017, but not adopted (Ministry of Economy, 2019). Importantly, the investigation could not clarify the reasons why these recommendations were not implemented. The company decided to start performing deep horizontal drains (DHP) in February 2018. On June 11, when the 15th DHP was drilled, a hydraulic fracture occurred in the initial embankment and the opening was suspended (Ministry of Economy, 2019). No other effective measures were taken by the company to lower the groundwater line of B1 until the break. Figure 1 points out the B1 timeline with the critical events, that is, occurrences that result in radical lasting transformations of the structure.

Figure 1 - B1 Dam Timeline



Source: Adapted from Ministry of Labor, 2019.
Note: DHP - Deep horizontal drain

Discussion about the case

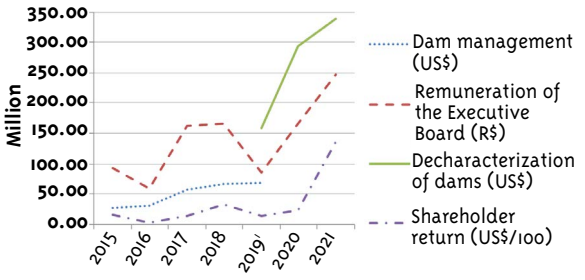
Figure 2 points out that the planned value for dam management was US$68 mi in 2019 and the value for dam decharacterization totaled US$338 mi in 2021 (Vale, 2016; 2017a; 2018a; 2019a; 2019d; 2020; 2021b; 2022b). Figure 2 also highlights the drop in dividend distribution and EO compensation between 2015 and 2016, as well as between 2018 and 2019, which relates to the end of the *commodities* megacycle and the drop in the value of the ton of iron ore (Wanderley, 2017). Between 2017 and 2018, dividend distribution grew again, was halted with the B1 breakup, but rose again strongly in 2020. EO compensation, on the other hand, came on the rise after 2016 and has not stopped since.

Investment in dam management saw modest growth between 2015 and 2019 (Figure 2), demonstrating that Vale had not yet recognized the problem. This is corroborated by the speech of the Executive Director of Ferrous Minerals, Mr. Gerd Peter Poppinga, during an investor event in London in 2015:

> As Luciano [CFO] said, in our 73-year history, we have never had a dam break. There are many things we

can do. You can upgrade your monitoring systems, by laser or radar, install more piezometers, and so on. This is what we are doing, and only just beginning. So far, we have no sign. We have nothing. We are fine with our governance and with the government, and we are fine with the integrity of the dams (Saes; Muradian, 2021).

Figure 2 - Investment in dam management and decharacterization, executive board compensation and dividend payments to Vale shareholders (2015-2021)



Source: Vale, 2012-2022.
Note: 1 - Predicted value for dam management in 2019.

Back in 2016, when he was presenting Vale's second quarter results, Poppinga declared:

> [...] no matter what will happen in terms specifically of upstream, the method of building tailings dams in Brazil in terms of legislation or restrictions, we can say that Vale, we don't have such dams. We don't, we have practically no upstream dams in operation [...] (Saes; Muradian, 2021).

The director downplayed the risk of Vale's dams, stating to investors that the company had "virtually" no upstream dams. But it was exactly B1, elevated upstream, that collapsed, an event followed by the interdiction of others of this type starting in 2019.

Marshall (2015, p. 172), through a survey applied to Vale workers in different countries, summarized some tactics employed by the company: "Vale unrealistically imposes high production targets; working at Vale means working in dangerous conditions, because they put production above all else [...]".

Marshall's (2015) research can illustrate how the company managed its mines and dams. As in the financial market, the results are obtained through management mechanisms considered violent, which exert pressure to achieve goals, interfere with and weaken the power to act of the professional collectives, introduce abusive cuts in strategic areas such as safety and maintenance, and outsource essential services, causing damage to safety and workers' physical and mental health (Takahashi et al., 2015).

The way Vale's EO was remunerated may have contributed to risky management of the facilities. This compensation was composed of a fixed part (monthly fee), a short-term variable part (annual bonus), and two long-term parts - the Virtual Stock Program (PAV) and *Matching* (Vale, 2019a; 2021a; 2022a).

By 2018, 60% of the annual bonus target dashboard was associated with economic-financial metrics that translated operational performance and were aligned to the dividend payout. PAV aligns the executives' focus to the shareholders' vision and has as its performance metric the *Total Shareholder Return* (TSR). TSR measures the return that an investment provides to the investor/shareholder, and also considers the share price fluctuation and dividend distribution, based on the period. *Matching* is based on the company's market value and the share price. It functions as a deferral of the annual bonus by converting part of the annual bonus payment paid to each director into shares and is mandatory for EO and voluntary for directors who are employees (Vale, 2019a; 2021a; 2022a).

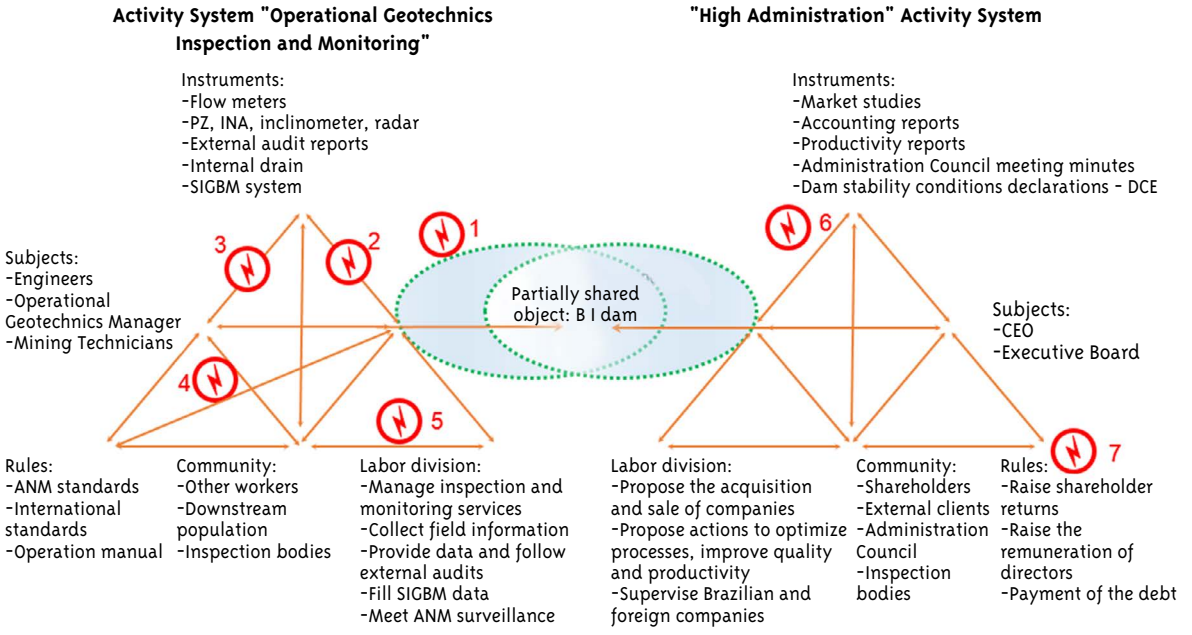
Bonus payments for top and middle management have already been studied in mining companies (Armstrong; Petter; Petter, 2019). The authors argue that bonus payments linked to financial system responses may encourage people to make decisions that bring short-term gains but risk long-term problems. By aligning the interests of top management with those of shareholders, they encourage the company to focus on maximizing financial return, even if this means taking higher risks of disastrous consequences.

Historical contradictions and dams

In this study, we analyze two AS: "Inspection and Monitoring" and "Top Management", both having a partially shared object, dam B1 (figure 3).

In the AS "Inspection and Monitoring", subjects were responsible for inspecting and monitoring B1, collecting field information, providing data to and following up with external auditors, entering data into SIGBM, and attending ANM inspection. "Top Management", composed of the CEO and executive directors, was responsible for proposing the acquisition and sale of companies; taking actions to optimize processes; improving quality and productivity; and supervising the group's companies in Brazil and abroad.

Figure 3 - Activity systems owned by Vale with a partially shared object.



Notes: ϟ - Contradiction; PZ - Piezometer; INA - Water level indicator; SIGBM - Mining dam information systems.

In 2017, after the change of Vale's president, the rules were changed. Shareholders were again well remunerated as in 2012 and EO had a jump in the amounts received. However, investment in dam safety has not kept up with this growth, a fact that seems to have contributed to the B1 break.

The investigation into the disaster pointed out that B1 stopped receiving tailings in July 2016 and, although it has continued to store waste released since 1976, it has had its use value diminished. Thinking strictly about this factor, Vale would have no reason to invest in works that would make B1 safer. The same reasoning can be used for the company's other dams that were no longer receiving tailings. Elevated upstream, B1 had a low construction value (value of exchange) compared to dams elevated downstream or on the centerline. In short, the construction of the B1 was low cost, but dangerous. This situation can be interpreted as a primary object contradiction, identified as "1" in figure 3.

As secondary contradictions (tensions between the elements of an AS), we can observe within "Inspection and Monitoring":

Contradiction 2 - between the instruments (insufficient and/or damaged monitoring equipment) and the shared object: it was not possible to have a safe dam with insufficient and/or damaged monitoring equipment.

Contradiction 3 - between instruments (external audit reports) and rules (international and Brazilian

standards): External audit reports pointed out a FS for undrained condition of B1 lower than required in international standards, something pointed out by consultants, since NBR 13028/2017 and ANM standards did not contemplate the minimum FS for such situation.

Contradiction 4 - between rule (operation manual) and shared object: it was not possible to have a safe dam without complying with the rules in the operation manual, such as the minimum width of the tailings beach.

Contradiction 5 - between division of labor (SIGBM data entry) and rules (ANM standard): data entry in SIGBM not complying with ANM standard.

We hypothesize two other secondary contradictions between elements of the AS "Top Management" and the partially shared object:

Contradiction 6 - between DCE instrument and object: "Top Management" understood that simply issuing the DCE brought safety to B1, which was not proven in the research findings.

Contradiction 7 - rule (increased dividends for shareholders) and the object: "Top Management" favored the financial market over the safety of B1.

The outsourcing of DCE moved regulation to private consulting that adopted legal as well as non-legally modeled regulation standards. The third one only recommends preventive measures. It turns out that TÜV SÜD, the company that issued B1's DCE in 2018, was also acting as a consultant to Vale on several other projects that it could lose if the dam did not receive a document attesting to its safety. As with British Petroleum, which experienced three major disasters between 2005 and 2010, Vale has apparently lost its ability to make balanced decisions about multidimensional problems - such as safety. As an aggravating factor, managers believed that no dam breaches in the past meant future safety, in a context of deregulation ideology and weakening state authority (Le Coze, 2017).

Only after the Brumadinho accident the problem was identified as chronic. The B1 dam was not an isolated case, as numerous other structures were fragile and were interdicted by public agencies. This leads us to point out that investments in dam management were insufficient.

Concluding remarks

In this article we try to demonstrate the contradictions in and between Vale's activity systems. The company distributed huge dividends to its shareholders, remunerated its directors as never before, reduced costs relative to revenues, and brutally reduced internal debt, but investments were insufficient in dam management, culminating in the B1 disaster in 2019 and the interdiction of 29 dams in 2021.

The metaphor of the Russian doll (Le Coze, 2017), adopted to explain layers of interpretation, applies to this case. The smaller doll is the dimension of technology and engineering, which ensures stability to the containment structures. This is overlaid by the layer of human and organizational aspects and a third layer of company transformations and strategies. The outermost layer refers to the changes adopted by the company in the face of globalization and major economic and political transformations, seeking to ensure permanent adaptations and considering all the actors involved in the company system and the other systems that could be affected in the event of a disaster. It is crucial to identify and reduce vulnerabilities and their respective processes - which are also their creators.

The B1 break prompted a broad mobilization of scientists and safety professionals who, in a fragmented way, studied different aspects of the history of the event. We point to a methodological path of interdisciplinary dialogue to help clarify how strategic managerial decisions, especially those of financial management, can influence the production, maintenance, and safety management of dams.

The analysis we conducted can be considered exploratory, but it allows us to point out the need for changes in the decision-making processes at the strategic and middle management levels of the organization involved. We join several authors in arguing that the pressure of the financial market and the way directors are remunerated contribute to decisions that bring short-term financial results, but with tragic long-term results.

References

ARCADIS. Caracterização socioambiental pós-rompimento e avaliação de impactos. In: ARCADIS. *Plano de reparação socioambiental da bacia do rio Paraopeba.* Rompimento das Barragens B1, B4 e B4-A do Complexo Paraopeba II da Mina Córrego do Feijão. São Paulo, 2020. Volume 1. Disponível em:

<https://www.mg.gov.br/sites/default/files/paginas/cap1_diagn%C3%B3stico_preterito_revisado/vol4_anexos/Volume%204_Anexos_pt1_2.pdf>. Acesso em: 11 jul. 2022.

ARMSTRONG M.; PETTER R.; PETTER, C. Why have so many tailings dams failed in recent years? *Resources Policy*, Amsterdam, v. 63, n. 1, 101412, 2019. DOI: 10.1016/j.resourpol.2019.101412

MINISTÉRIO DA ECONOMIA. Superintendência Regional do Trabalho em Minas Gerais. *Relatório de Análise de Acidente*: rompimento da barragem de Rejeitos I, em Brumadinho - MG. Belo Horizonte, 2019. Disponível em: <https://sinait.org.br/docs/305346580-relatorio_bi_-_a_corpo_assinado.pdf>. Acesso em: 26 fev. 2021.

BRASIL. Ministério das Minas e Energia. Agência Nacional de Mineração. Portaria n° 70.389, de 17 de maio de 2017. *Diário Oficial da União*. Seção 1, Brasília, DF, Ano 154, n. 95, p. 68-71, 19 mai. 2017.

BRASIL. Ministério das Minas e Energia. Resolução nº 4, de 15 de fevereiro de 2019. *Diário Oficial da União*. Seção 1, Brasília, DF, Ano 157, n. 34, p. 58, 18 fev. 2019a.

BRASIL. Ministério das Minas e Energia. *Resumo Campanha Entrega DCE Setembro 2019*. Brasília, DF: Ministério das Minas e Energia, 2019b. Disponível em: <https://www.gov.br/anm/pt-br/assuntos/barragens/declaracao-de-condicao-de-estabilidade-dce/resumo-campanha-entrega-dce-setembro-2019/>. Acesso em: 28 maio 2021.

BRASIL. Ministério das Minas e Energia. *Resumo Campanha Entrega DCE Março 2020*. Brasília: Ministério das Minas e Energia, 2020a. Disponível em: <https://www.gov.br/anm/pt-br/assuntos/barragens/declaracao-de-condicao-de-estabilidade-dce/resumo-campanha-entrega-dce-marco-2020/view>. Acesso em: 28 maio 2021.

BRASIL. Ministério das Minas e Energia. *Resumo Campanha Entrega DCE Setembro 2020*. Brasília, DF: Ministério das Minas e Energia, 2020b. Disponível em: <https://www.gov.br/anm/pt-br/assuntos/barragens/declaracao-de-condicao-de-estabilidade-dce/resumo-campanha-entrega-dce-setembro-2020>. Acesso em: 27 dez. 2022.

BRASIL. Ministério das Minas e Energia. *Resumo Campanha Entrega DCE Março 2021*. Brasília: Ministério das Minas e Energia, 2021a. Disponível em: <https://www.gov.br/anm/pt-br/assuntos/barragens/declaracao-de-condicao-de-estabilidade-dce/resumo-campanha-entrega-dce-mar2021.pdf>. Acesso em: 27 dez. 2022.

BRASIL. Ministério das Minas e Energia. *Resumo Campanha Entrega DCE Setembro 2021*. Brasília, DF: Ministério das Minas e Energia, 2021b. Disponível em: <https://www.gov.br/anm/pt-br/assuntos/barragens/declaracao-de-condicao-de-estabilidade-dce/resumo-campanha-entrega-dce-set2021-v2.pdf>. Acesso em: 27 dez. 2022.

BRASIL. Ministério das Minas e Energia. *Resumo Campanha Entrega DCE Setembro 2022*. Brasília, DF: Ministério das Minas e Energia, 2021b. Disponível em: https://www.gov.br/anm/pt-br/assuntos/barragens/declaracao-de-condicao-de-estabilidade-dce/resumo-campanha-entrega-dce-setembro-de-2022.pdf. Acesso em: 27 dez. 2022.

CRUZ, P.T. *100 Barragens brasileiras*: casos históricos, materiais de construção, projeto. São Paulo: Oficina de Textos, 1996.

CUNHA R. Auditores do trabalho interditam nove barragens da Vale em Minas. *Hoje em dia*, Belo Horizonte, 10 abr. 2019. Disponível em: <http://hoje.vc/2dsoa>. Acesso em: 7 mar. 2021.

DIAS A.V.; LIMA F.A.P. Work organization and occupational health in the contemporary capitalism. In: RIBEIRO, M. G. (Ed.). *Frontiers in occupational health and safety*, 2014. p. 3-31. v. 1

FEAM – Fundação Estadual do Meio Ambiente. *Inventário de Barragens 2017*. Belo Horizonte, 2017.

Disponível em: <http://www.feam.br/gestao-de-barragens/inventario-de-barragens>. Acesso em: 7 mar. 2021.

FEAM - Fundação Estadual do Meio Ambiente. *Inventário de Barragens 2018*. Belo Horizonte, 2018. Disponível em: <http://www.feam.br/gestao-de-barragens/inventario-de-barragens>. Acesso em: 7 mar. 2021.

LE COZE, J. C. Globalization and high-risk systems. *Policy and practise and health and safety*, London, v. 15, p. 57-81, 2017. DOI: 10.1080/14773996.2017.1316090

LOPES M.G.R.; VILELA R.A.G.; QUEROL M.A.P. Anomalias e contradições do processo de construção de um aeroporto: uma análise histórica baseada na Teoria da Atividade Histórico-Cultural. *Cadernos de Saúde Pública*, Rio de Janeiro, v. 34, n. 2, e00130816, 2018. DOI: 10.1590/0102-311X00130816

METZGER J.L.; MAUGERI S.; BENEDETTO-MEYER M. Predomínio da gestão e violência simbólica. *Revista Brasileira de Saúde Ocupacional*, São Paulo, v. 37, n. 126, p. 225-242, 2012. DOI: 10.1590/S0303-76572012000200005

MARSHALL J. Behind the image of south-south solidarity at Brazil's Vale. In: BOND, P; GARCIA A. (org.). *BRICS*: An anti-capitalism critique. Chicago: Haymarket Books, 2015. p. 162-185.

MILANEZ B. et al. Minas não há mais: avaliação dos aspectos econômicos e institucionais do desastre da Vale na bacia do rio Paraopeba. *Versos - Textos para discussão PoEMAS*, Brasília, DF, v. 3, n. 1, 2019.

RASMUSSEN J. Risk management in a dynamic society: a modeling problem. *Safety Science*, Amsterdam v. 27, n. 2/3, p. 183-213, 1997.

REASON J. *Managing the risks of organizational accidents*. Farnham: Ashgate Publishing, 1997.

SAES, B.; MURADIAN, R. What misguides environmental risk perceptions in corporations? Explaining the failure of Vale to prevent the two largest mining disasters in Brazil. *Resources Policy*, Amsterdam, v. 72, 2021. DOI: 10.1016/j.resourpol.2021.102022

TAKAHASHI M.A. et al. Gestão violenta e patologia organizacional: reflexões para uma intervenção articulada entre academia, serviços e movimento sindical. *Revista Ciências do Trabalho*, São Paulo, n. 4, p. 27-47, 2015.

VALE. *Formulário 20 F*. Relatório anual para o exercício encerrado em 31 de dezembro de 2011. Rio de Janeiro, 2012. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/cd552a7e-7544-4be0-8f6d-3028afe578d8?origin=1>. Acesso em: 6 mar. 2023.

VALE. *Formulário 20 F*. Relatório anual para o exercício encerrado em 31 de dezembro de 2012. Rio de Janeiro, 2013. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/7ca1afb2-b102-45db-9980-b703372de660?origin=1>. Acesso em: 6 mar. 2023.

VALE. *Formulário 20 F*. Relatório anual para o exercício encerrado em 31 de dezembro de 2013. Rio de Janeiro, 2014. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/718f125c-d4ac-43b8-b084-c4448dd1cd52?origin=1>. Acesso em: 6 mar. 2023.

VALE. *Formulário 20 F*. Relatório anual para o exercício encerrado em 31 de dezembro de 2014. Rio de Janeiro, 2015. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/92cdcd62-9b93-4195-8cd7-fb985cc63e88?origin=1>. Acesso em: 6 mar. 2023.

VALE. *Formulário 20 F*. Relatório anual para o exercício encerrado em 31 de dezembro de 2015. Rio de Janeiro, 2016. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/ad6bc0d7-89b8-4eb8-b6f6-4d71f5158b76?origin=1>. Acesso em: 6 mar. 2023.

VALE. *Formulário 20 F*. Relatório anual para o exercício encerrado em 31 de dezembro de 2016. Rio de Janeiro, 2017a. Disponível em:

<https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/36671c36-0a4c-4e65-81b4-1ac4c149bdae?origin=1>. Acesso em: 6 mar. 2023.

VALE. *Formulário 20 F*. Relatório anual para o exercício encerrado em 31 de dezembro de 2017. Rio de Janeiro, 2018a. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/c82de250-86e5-4d60-8d96-669b6732a105?origin=1>. Acesso em: 6 mar. 2023.

VALE. *Formulário 20 F*. Relatório anual para o exercício encerrado em 31 de dezembro de 2018. Rio de Janeiro, 2019a. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/0b52c197-9c7e-4c67-b3f4-c60d658cfode?origin=1>. Acesso em: 6 mar. 2023.

VALE. *Formulário 20 F*. Relatório anual para o exercício encerrado em 31 de dezembro de 2019. Rio de Janeiro, 2020a. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/d097db59-c956-4aa4-9d64-6b55d82fb0a4?origin=1>. Acesso em: 6 mar. 2023.

VALE. *Formulário 20 F*. Relatório anual para o exercício encerrado em 31 de dezembro de 2020. Rio de Janeiro, 2021b. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/6425a6c6-6caf-41c2-ab60-f848dda39fb7?origin=1>. Acesso em: 6 mar. 2023.

VALE. *Formulário 20 F*. Relatório anual para o exercício encerrado em 31 de dezembro de 2021. Rio de Janeiro, 2022b. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/102c9ca4-dea3-7079-6576-38d6a6d8917b?origin=1>. Acesso em: 6 mar. 2023.

VALE. *Formulário de referência 2018*. Rio de Janeiro, 2019a. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/41c08169-c924-4ecf-a48f-61779367bd4d?origin=1>. Acesso em: 13 out. 2022.

VALE. *Formulário de referência 2021*. Rio de Janeiro, 2021a. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/95362b5d-56b4-1317-3eab-3cf2a928a9ad?origin=1>. Acesso em: 13 out. 2022.

VALE. *Formulário de referência*, versão 3, 2022. Rio de Janeiro, 2022a. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/95362b5d-56b4-1317-3eab-3cf2a928a9ad?origin=2>. Acesso em: 27 abr. 2022.

VALE. *Relatório de sustentabilidade 2016*. Rio de Janeiro, 2017b. Disponível em: <https://api.mziq.com/mzfilemanager/v2/d/53207d1c-63b4-48f1-96b7-19869fae19fe/de5a44e5-22fa-4e38-9484-fa70694ed479?origin=1>. Acesso em: 20 maio 2022.

VALE. *Relatório de sustentabilidade 2017*. Rio de Janeiro, 2018b. Disponível em: <https://vale.com/documents/d/guest/v_vale_relatoriosustentabilidade_2017_v>. Acesso em: 13 out. 2022.

VALE. *Vale conclui a descaracterização da primeira das nove barragens a montante anunciadas no início do ano*. Rio de Janeiro, RJ, 2019b. Disponível em: http://saladeimprensa.vale.com/Paginas/Releases.aspx?r=Vale_conclui_a_descaracterizacao_da_primeira_das_nove_barragens_a_montante_anunciadas_no_inicio_do_ano&s=Mineracao&rID=2511&sID=6. Acesso em: 26 fev. 2021.

VALE. *Vale informa sobre Declarações de Condição de Estabilidade*. Rio de Janeiro, RJ, 2019c. Disponível em: http://saladeimprensa.vale.com/Paginas/Releases.aspx?r=Vale_informa_sobre_Declaracoes_de_Condicao_de_Estabilidade&s=Mineracao&rID=2378&sID=6. Acesso em: 7mar. 2021.

VALE. *Vale informa que o investimento em gestão de barragens cresce 180% entre 2015 e 2019*. Rio de Janeiro, RJ, 2019d. Disponível em: http://saladeimprensa.vale.com/Paginas/Releases.aspx?r=Investimento_em_gestao_de_barragens_cresce_180_entre_2015_e_2019&s=Mineracao&rID=2299&sID=6. Acesso em: 7 mar. 2021.

VIRKKUNEN, J.; NEWNHAM, D.S. *O laboratório de mudança*: uma ferramenta para o desenvolvimento colaborativo do trabalho e a educação. Belo Horizonte: Fabrefactum, 2015.

WANDERLEY L. J. de M. Do *boom* ao pós-*boom* das commodities: o comportamento do setor mineral no Brasil. Versos - Textos para discussão PoEMAS, Belo Horizonte, v. 1, n. 1, 2017.

WISE Uranium Project. *Chronology of major tailings dam failures from 1960.* Arnsdorf, 2020. Disponível em: <https://www.wise-uranium.org/mdaf.html>. Acesso em: 15 maio 2021.

Authors' contribution

Botelho and Vilela participated in the conception, study design and writing of the article. Vilela, Beltran, Almeida and Querol were responsible for the critical review of the article. All authors participated in the analysis and interpretation of the data, as well as approved the version to be published.

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